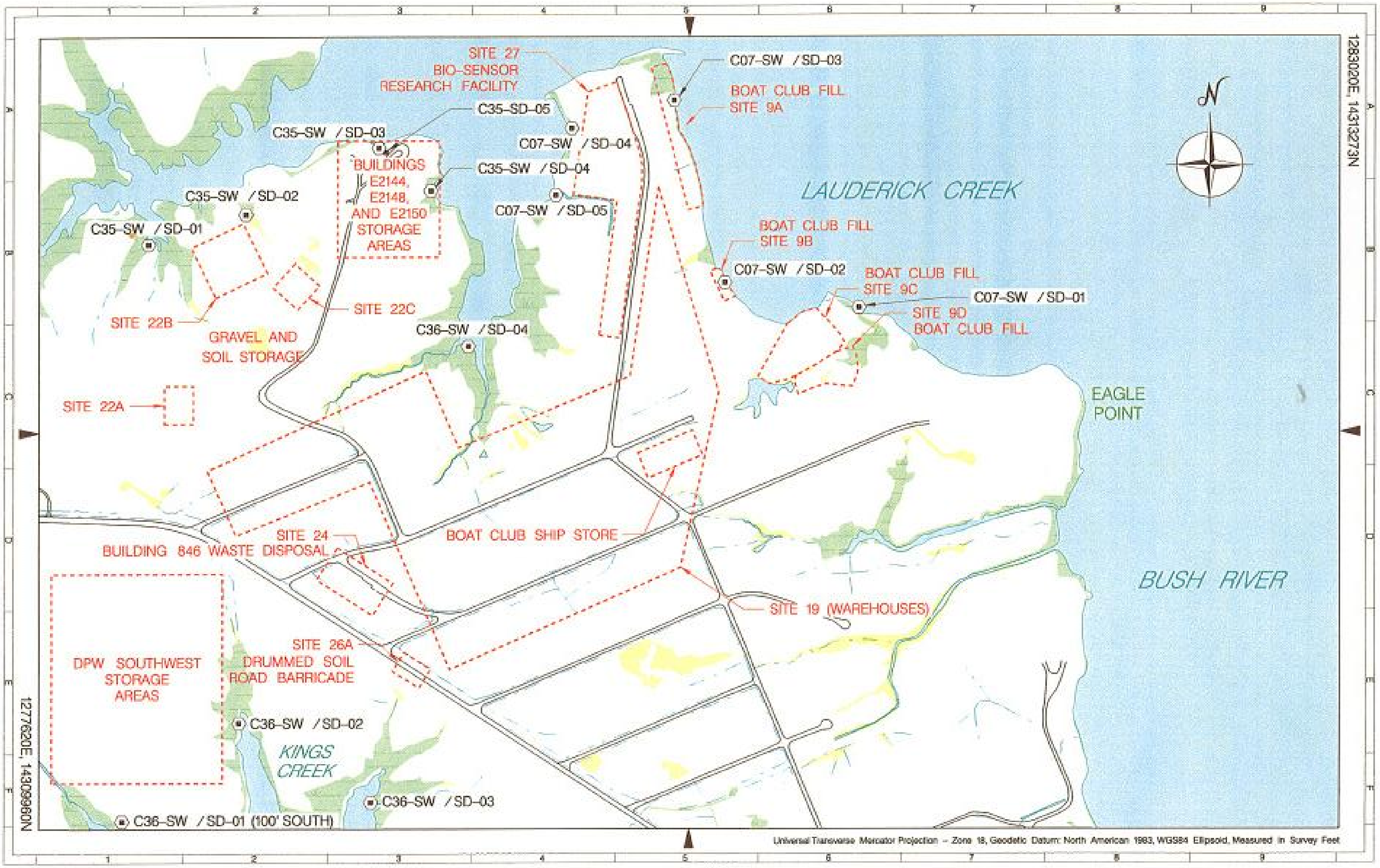
Table 2-4. Northern Bush River RI Program Analytical Parameters and Methods (continued)

Parameter	Matrix	Method
General chemical Constituents		
Fluoride	Groundwater	EPA-600 340.2
Silica, Dissolved	Groundwater	SW-846 6010
Bromide	Groundwater	EPA-600 300.0 or 320.1
		EPA-600 212.3
Boron	Water	
Total Suspended Solids	Surface Water	EPA 160.2
Total Dissolved Solids	Groundwater	EPA-600 160.1 or 160.3
Nitrate as Nitrogen	Groundwater	EPA-600 353.2
Hardness, Total	Water	EPA-600 130.1 or 130.2
Alkalinity, Total	Water	EPA-600 310.1
Sulfate	Groundwater	EPA-600 375.3 or 375.4M
Sieve Analysis	Solids	ASTM 422
Total Organic Carbon	Solids	SW-846 9060

[1]Only Cluster 7 sediment, soil, and sludge samples analyzed for gamma spectral analysis.

American Society for testing and Materials (ASTM) method 422
United States Army Environmental Center (USAEC). 1985. Diisopropylmethylphosphonate/Dimethylmethylphosphonate in Environmental Water Samples, Method T8M.
-----. 1986a. Diisopropylmethylphosphonate/Dimethylmethylphosphonate in Environmental Soil Samples, Method TT9.
-----. 1988a. Determination of Organosulfur Compounds in Water by Gas Chromatography, Method UL04.
-----. 1988b. Determination of Organosulfur Compounds in Soil by Gas Chromatography, Method LL03.
-----. 1989a. Analysis of Thiodiglycol and Thiodiglycolic Acid in Environmental Water Samples, Method UW22.
-----. 1989b. Analysis of Thiodiglycol and Chloroacetic Acid in Environmental Soil Samples, Method LW18.
-----. 1990. Isopropylmethylphosphonic Acid, Methylphosphonic Acid, and Fluoroacetic Acid in Water, Method UT02.
-----. 1992. Isopropylmethylphosphonic Acid, Methylphosphonic Acid, and Fluoroacetic Acid in Soil, Method AAA9.
United States Environmental Protection Agency (USEPA). 1986. Test Methods for Evaluating Solid Waste. Office of Solid Waste and Emergency Response.
-----. 1988. EPA 600 Series. 40 code of Federal Regulations, Part 136
-----. 1991a. Contract Laboratory Program (CLP) Statement of Work for Organic Analysis, Multi-Media, Multi-Concentration. Revision Number OLM01.8.
-----. 1991b. Contract Laboratory Program Statement of Work for Inorganics Analysis, Multi-Media, Multi-Concentration. Revision Number ILM 03.0.
-----. 1991c. Methods for chemical analysis of wastewater (MCAWW).



L E G E N D

	Water	—	Road
	Tidal Wetland	–·–	Stream / Drainage Ditch
	Non-tidal Wetland	- - -	Site Boundary
■	Sediment Sample	⊙	Surface Water / Sediment Sample

600 400 200 0 300 600 1200

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TITLE:
NORTHERN BUSH RIVER SURFACE WATER AND SEDIMENT SAMPLING LOCATIONS

CARTOGRAPHER:	APPROVED BY:	DATE:	FIGURE:
B. JOYCE	T. DEREAMER	02-07-02	2-3

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Table 2-5. Surface Water, Sediment, Soil, Sludge Sample Points Correlated to Northern Bush River Sites

Site Name	Sample Media	Sample Designation[1]	Relationship
Boat Club Fill Sites (Sites 9A, 9B, 9C, 9D)	Surface Water and Sediment	C07-SW/SD-01	Downgradient of drainage from Sites 9C and 9D
		C07-SW/SD-02	Downgradient of drainage from Site 9B
		C07-SW/SD-03	Downgradient of drainage from Site 9A
	Surface Soil	C07-SS-04	Downgradient of Site 9B
		C07-SS-05, C07-SS-06	Within Site 9A
		C07-SS-15	Within Site 9C
		C07-SS-16	Within Site 9D
	Subsurface Soil	C07-SO-01, C07-SO-12, CO7-SO-13	Within Site 9D
		C07-SO-02, C07-SO-03, C07-SO-11	Within Site 9C
		C07-SO-10	Within Site 9A
Bio-Sensor Research Facility (Site 27)	Surface Water and Sediment	C07-SW/SD-04	Downgradient of drainage from the wastewater package treatment plant chlorination chamber
		C07-SW/SD-05	Downgradient of drainage south of former dog kennel area
	Surface Soil	C07-SS-07	Within wastewater package treatment plant septic field
		C07-SS-14	Within drainage ditch downgradient from and southwest of site
	Subsurface Soil	C07-SO-08	Within wastewater package treatment plant septic field
	Sludge	C07-SL-09	Within wastewater package treatment plant chlorination chamber
Gravel and Soil Storage (Sites 22A, 22B, 22C)	Surface Water and Sediment	C35-SW/SD-01, C35-SW/SD-02	Downgradient of drainage north of Sites 22A and 22B
	Surface Soil	C35-SS-01, C35-SS-02	Within drainage downgradient from Site 22A
		C35-SS-03, C35-SS-04	Within Site 22B
		C35-SS-05	Within drainage downgradient from and north of Site 22B
		C35-SS-06	Within Site 22C
		C35-SS-12	Within drainage downgradient from and southeast of Site 22C

Table 2-5. Surface Water, Sediment, Soil, and Sludge Sample Points Correlated to Northern Bush River Sites (continued)

Site Name	Sample Media	Sample Designation[1]	Rationale
Buildings E2144, E2148, and E2150 (Unnumbered)	Surface Water and Sediment	C35-SW/SD-03	Downgradient of drainage between Buildings E2148 and E2150
		C35-SW/SD-04	Downgradient of drainage south of Building E2150
		C35-SD-05	Within munitions disposal area along Lauderick Creek shoreline
		C36-SW/SD-04	Downgradient of drainage from Building E2144
	Surface Soil	C35-SS-07, C35-SS-13	Within drainage down radient from and northeast and west of Building E2148, respectively
		C35-SS-08, C35-SS-14	Within drainage downgradient from and west and north of Building E2150, respectively
		C35-SS-09	Near former metal storage racks southeast of Building E2148
		C35-SS-10, C35-SS-11	Within drainage downgradient from and southeast and northeast of Building E2144, respectively
Warehouse Storage Areas (Site 19)	Surface Water And Sediment	C36-SW/SD-04	Downgradient of drainage north of warehouses E2166, E2168, and E2170
	Surface Soil	C36-SS-12	Within drainage downgradient from and north of Buildings E2166 and E2168
Building 846 (E2194) Waste Disposal Site (Site 24)	Surface Soil	C36-SS-07, C36-SS-08	Downgradient of site
Drummed Soil Road Barricade Site (Site 26A)	Surface Water and Sediment	C36-SW/SD-03	Downgradient of drainage from south of site
	Surface Soil	C36-SS-03, C36-SS-04, C36-SS-05	Within drainage downgradient from and south of site
		C36-SS-06	Within Site
Boat Club Ship Store (E2169) (Unnumbered)	Sludge	C36-SL-11	Within septic tank associated with Building E2169
DPW Southwest Storage Areas (Unnumbered)	Surface Water and Sediment	C36-SW/SD-01, C36-SW/SD-02	Down radient of drainage south and southeast of site, respectively
	Surface Soil	C36-SS-01, C36-SS-02	Within drainage downgradient of southern and eastern portions of site, respectively

[1]Surface water/sediment and soil samples are potentially downgradient or upgradient from other sites.

SW/SD=Surface Water/Sediment sample
SS=Surface Soil sample
SL=Sludge sample
SO=Subsurface Soil sample

C07=Cluster 07
C35=Cluster 35
C36=Cluster 36

2.7.1 Soil Gas Survey

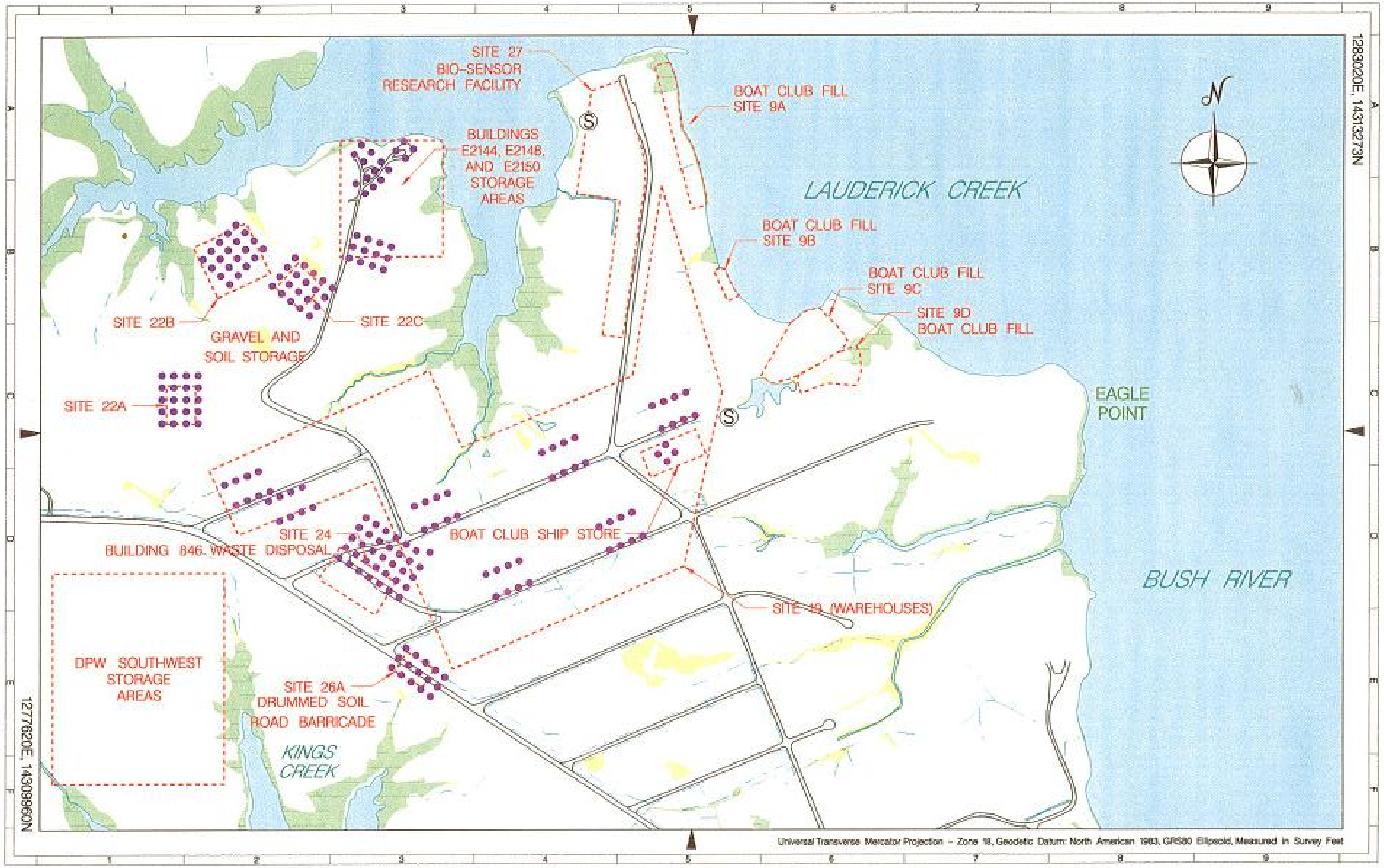
GP conducted a passive soil gas survey at the Cluster 35 Gravel and Soil Storage (Sites 22A, 22B, and 22C) and Buildings E2144, E2148, E2150; and Cluster 36 Warehouse Storage Areas (Site 19), Building 846 (E2194) Waste Disposal Site (Site 24), Drummed Soil Road Barricade Site (Site 26A), and the Boat Club Ship Store (Building E2169) during August 1994. Figure 2-4 shows the soil gas survey locations. The soil gas survey was used as a screening tool to gather sufficient information to qualitatively evaluate the distribution of VOCs and selected SVOCs in the vadose zone at these sites.

GP performed the passive soil gas investigation using the Gore-Sorber® method from August 1, 1994 through August 19, 1994 in accordance with SOP 027A of Appendix J to the Generic Work Plan (W.L. Gore & Associates, Inc., 1994). After the explosive ordnance disposal contractor cleared the sampling locations for UXO using a magnetometer, personnel installed a total of 198 passive soil gas collectors approximately 3-feet below the ground surface at 50-foot intervals. Field personnel placed 20 modules at the Cluster 35 Gravel and Soil Storage Sites 22A, 22B, and 22C; 12 modules at Building E2144, 12 modules east and southeast of Building E2148, and four modules west of Building E2150; eight modules (four on each side) at seven Cluster 36 Warehouse Storage Areas (i.e., E2160, E2162, E2166, E2168, E2170, E2196, and E2198); 35 modules at the Building 846 (E2194) Waste Disposal Site 24; 15 modules at the Drummed Soil Road Barricade Site 26A; and four modules east of the Boat Club Ship Store (Building E2169).

After 14 days, GP removed and transported the 198 modules to SciTech Services, Inc. for chemical warfare agent screening. All samples tested negative for chemical agent compounds. W.L. Gore & Associates, Inc. then analyzed the modules for VOCs and selected SVOCs. The samples were analyzed by gas chromatography and mass selective detection, as well as thermal desorption with cryofocusing. The mass spectrometer measures the amount of VOCs present by ion counts, which show the relative intensities of each of the reported compounds. These response levels do not represent an actual concentration of the reported compound, but instead differentiate areas of relatively high ion counts from areas of relatively low ion counts. Section 4 summarizes the results of the soil gas survey.

2.7.2 Surface Soil and Sludge Sampling and Analysis

As part of the Northern Bush River RI program, GP collected one round of surface soil samples at 30 locations and two sludge samples from separate underground septic tanks for chemical analysis at designated dates between January 1995 and June 1996. Figure 2-5 depicts the surface soil and sludge sample locations. Table 2-3 presented the dates of each surface soil and sludge sampling event, and the sample locations associated with each event. The primary purpose for collecting these samples was to assess the surface and subsurface migration pathways from known or potential sources, and provide



LEGEND

Water	Road
Tidal Wetland	Stream / Drainage Ditch
Non-tidal Wetland	Site Boundary
Septic Tank	Soil Gas Point

600 400 200 0 300 600 1200

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TITLE:

NORTHERN BUSH RIVER
SOIL GAS SURVEY LOCATIONS

CARTOGRAPHER:	APPROVED BY:	DATE:	FIGURE:
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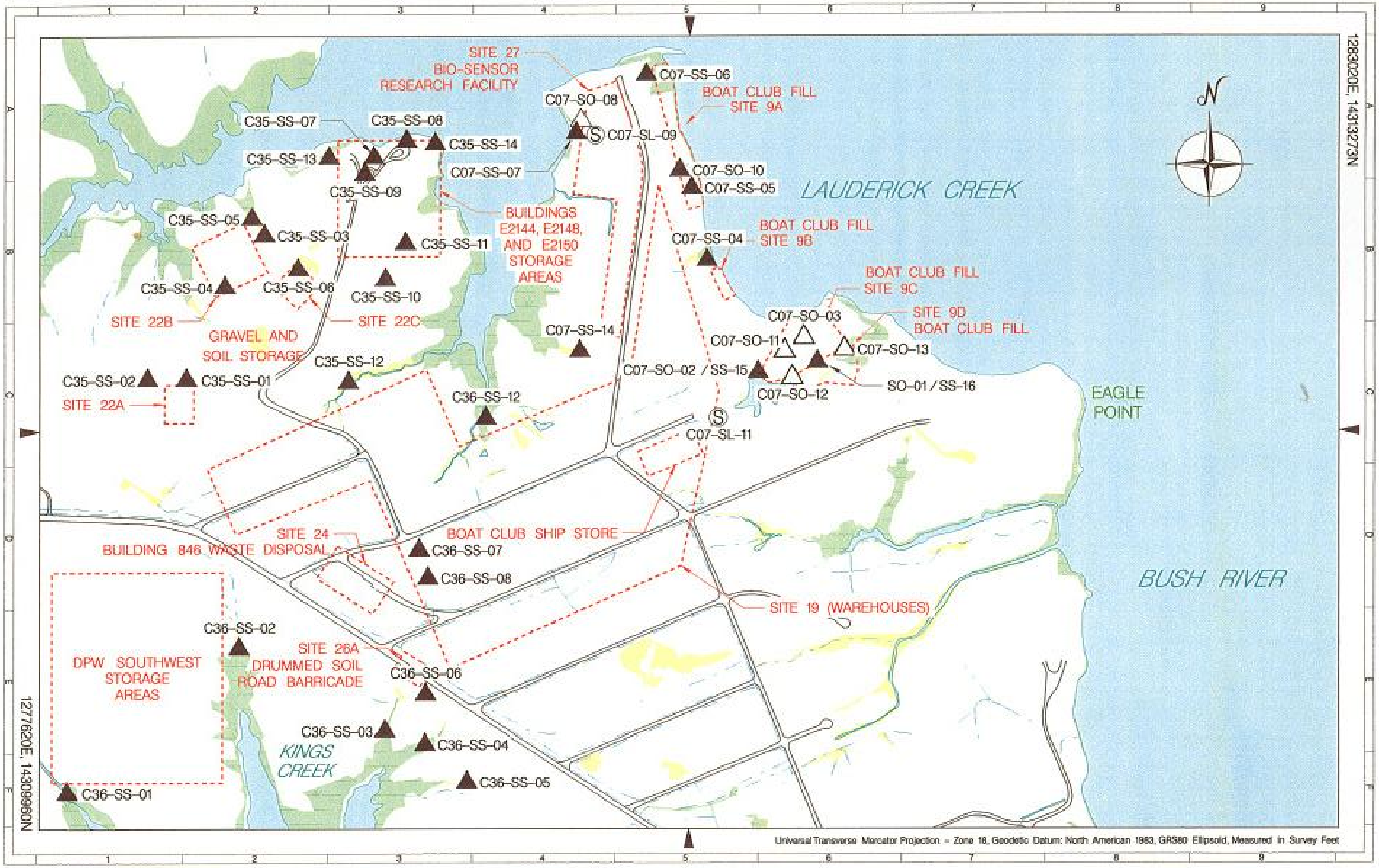

L E G E N D

- Water
- Tidal Wetland
- Non-tidal Wetland
- Road
- Stream / Drainage Ditch
- Site Boundary
- Sludge Sample
- Surface Soil Sample
- Subsurface Soil Sample

600 400 200 0 300 600 1200

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NORTHERN BUSH RIVER SURFACE SOIL, SUBSURFACE SOIL AND SLUDGE LOCATIONS			
CARTOGRAPHER:	APPROVED BY:	DATE:	FIGURE:
B. JOYCE	T. DEREAMER	01-22-03	2-5

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sufficient data to perform a risk assessment. Table 2-5 outlined the sample location relationship by showing the correlation of surface soil and sludge sampling points to potential source areas in Northern Bush River.

GP collected 30 surface soil samples and five duplicates from one round of sampling for chemical analysis in accordance with SOP 025 of Appendix J to the Generic Work Plan. GP also collected two sludge samples, one from the Boat Club Ship Store (Building E2169) septic tank (labeled C36-SL-11) and one from a chlorination chamber associated with the former Bio-Sensor Research Facility wastewater package treatment plant (labeled C07-SL-09), in accordance with SOP 025 of Appendix J to the Generic Work Plan. Because little or no sludge existed in the tanks, water samples were collected and analyzed. The RI Sampling and Analysis Reports for Northern Bush River present the details of the surface soil and sludge sampling (GP, 1995c and 1996; Earth Tech, Inc and GP, 1996b).

Before collection of samples for chemical analysis at an off-site analytical laboratory, a composite sample from each location was collected for chemical warfare agent screening, in accordance with SOP 035 of Appendix J to the Generic Work Plan. GP submitted all samples to the Chemical Transfer Facility for initial headspace analysis of HD, GB, GD, and VX. After the samples cleared headspace analysis, the samples were transported to the on-post SciTech Services, Inc. laboratory for further low-level laboratory analyses. All samples tested negative for chemical agent compounds. Sampling teams collected all surface soil samples up to a depth of 6 inches beneath the ground surface.

General Physics Environmental Services analyzed the surface soil and sludge samples for the presence of analytes found on the TCL and TAL, explosives-related compounds, chemical agent degradation products, general chemical constituents and physical properties, and radiological parameters. STEP validated the data (STEP, 1996 a through d). Table 2-3 also presented the type and number of field QA/QC samples collected per sampling event. All sample containers were labeled, secured, preserved, and shipped in accordance with SOPs 001, 002, 039, and 004 of Appendix J to the Generic Work Plan. Table 2-4 listed the analytical parameters and methods used during the RI surface soil and sludge sampling program. Section 4 summarizes results of the surface soil and sludge sampling.

2.7.3 Subsurface Soil Sampling and Analysis

As part of the Northern Bush River RI program, GP collected one round of subsurface soil samples for chemical analysis at eight locations within the Cluster 7 Boat Club Fill Sites 9A, 9B, 9C, and 9D, and the Bio-Sensor Research Facility (Site 27) from June 10 to 12, 1996. Figure 2-5 depicted the subsurface soil sample locations. Table 2-3 presented the dates of the subsurface

soil sampling event and the sample locations associated with each event. The primary purpose for collecting these samples was to assess the subsurface migration pathways from known or potential source areas, and provide sufficient data to perform a risk assessment. Table 2-5 outlined the sample location relationship by showing the correlation of subsurface soil sampling points to potential source areas in Northern Bush River.

GP collected seven subsurface soil samples from locations C07-SO-01 through C07-SO-03 and C07-SO-10 through C07-SO-13 to characterize the fill material at Boat Club Fill Sites 9A, 9B, 9C, and 9D; and the remaining subsurface soil sample from location C07-SO-08 to characterize the former wastewater package treatment plant within the Bio-Sensor Research Facility in accordance with SOP 025 of Appendix J to the Generic Work Plan. Field personnel obtained subsurface soil samples by collecting composite samples from each sampling location at 6 inches, 2 feet, and 4 feet below ground surface. Due to auger refusal at a depth of 3.5 feet, subsurface soil sample location C07-SO-03 consisted of a composite at 6 inches, 2 feet, and 3.5 feet below ground surface. Samples for VOCs were not composite samples. An RI Sampling and Analysis Report for Northern Bush River presents details of the subsurface soil sampling (Earth Tech, Inc. and GP, 1996b).

Before collection of samples for chemical analysis at an off-site analytical laboratory, a composite sample from each sample location was collected for chemical warfare agent screening in accordance with SOP 035 of Appendix J to the Generic Work Plan. GP submitted all samples to the Chemical Transfer Facility for initial headspace analysis of HD, GB, GD, and VX. After the samples cleared headspace analysis, the samples were transported to the on-post SciTech Services, Inc. laboratory for further low-level laboratory analysis. All samples tested negative for chemical agent compounds.

General Physics Environmental Services analyzed the subsurface soil samples for the presence of analytes found on the TCL and TAL, explosive-related compounds, chemical agent degradation products, general chemical constituents and physical properties, and radiological parameters. STEP validated the data (STEP, 1996a and b). Table 2-3 presented the type and number of field QA/QC samples collected per sampling event. All sample containers were labeled, secured, preserved, and shipped in accordance with SOPs 001, 002, 039, and 004 of Appendix J to the Generic Work Plan. Table 2-4 listed the analytical parameters and methods used during the RI subsurface soil sampling program. Section 4 summarizes results of subsurface soil sampling.

2.8 Summary and Results of Removal Actions

Concurrent with the RI activities performed at Northern Bush River, DSHE initiated a removal action that mitigated environmental and health hazards presented by potentially contaminated surface waste located throughout the entire Bush River Study Area. During May of 1996, the ERDEC (now ECBC) Chemical Support Division completed removal of potentially contaminated surface waste and rubble from past outdoor operations conducted throughout the Bush River Study Area. The purpose of this removal action was to minimize any potential release and migration of contaminants from surface material and rubble into the environment. The potentially contaminated surface material within the Bush River Study Area included corroded metal of various sizes and origins (e.g., empty drums, containers, and expended UXO remnants), and any discarded material or debris associated with chemical warfare training operations (e.g., gas mask filters, protective clothing, etc.). Removal personnel placed all recovered surface material and rubble into wooden crates, and sealed the crates with a plastic cover. The ERDEC (now ECBC) Monitoring Branch monitored the headspace of each crate for chemical agent material. After headspace monitoring of a crate indicated negative responses for chemical agent compounds, ERDEC transported each crate to the Decontamination/Detoxification facility located the Edgewood Area for thermal treatment (ERDEC, 1996). In addition, the U.S. Army Technical Escort Unit removed approximately 10, 75-millimeter rounds from a disposal site on the Lauderick Creek Shoreline in 1995 at location C35-SD-05 (Figure 2-3). All samples tested negative for chemical agent compounds.

3.0 Physical Characteristics

3.0 PHYSICAL CHARACTERISTICS OF STUDY AREA

This section discusses the physical characteristics based on the results of physical investigations at the Northern Bush River Area, and reference documents of the Bush River Study Area and APG. This section summarizes meteorology, surface features and drainage patterns, regional and localized geology, hydrogeology, and groundwater recharge and discharge areas. Discussion also includes subsurface features, ecology, and human population and land-use information concerning Northern Bush River and the surrounding region.

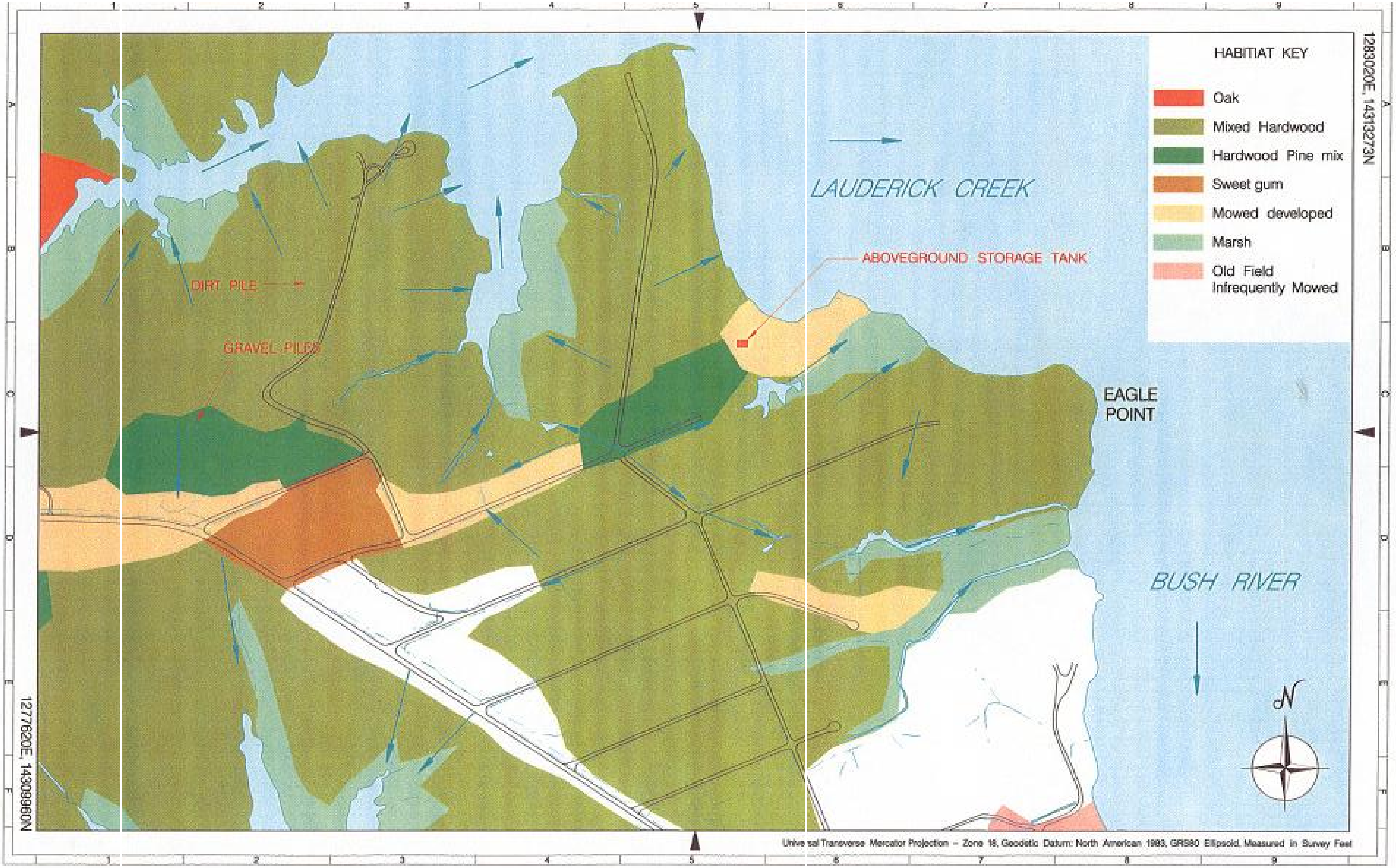
3.1 Meteorology

The Edgewood Area of APG experiences a modified temperate climate. The Edgewood Area's proximity to the Chesapeake Bay, the Atlantic Ocean, and Appalachian Mountains effects the general atmospheric circulation of the area. These atmospheric effects by the ocean and the mountains prevent APG from having a typical mid-latitude temperate climate. Winters are humid and generally milder than in the inland areas, and summers are hot and humid with frequent thunderstorms. Mean annual air temperature is approximately 54°F. Mean daily temperatures generally range from 34°F in the winter months to 75°F in the summer. Temperatures commonly exceed 90°F during the summer months and are accompanied by high humidity yielding a subtropical climate. The average relative humidity is 74 percent. The warmest period of the year is during the last half of July, and the coldest period of the year is during the end of January and the beginning of February. Average annual precipitation is approximately 45 inches. The distribution of monthly precipitation is fairly uniform throughout the year; the maximum precipitation occurs in May and the minimum precipitation occurs in February (Atmospheric Sciences Laboratory, 1985).

Prevailing winds are from the west to northwest in the fall and winter and from the south to southwest in the spring and summer. Average annual wind velocity ranges from six to 10 miles per hour, but can reach 50 to 60 miles per hour and higher during severe storms (Atmospheric Sciences Laboratory, 1985).

3.2 Surface Features and Drainage

The Northern Bush River Area encompasses approximately 230 acres with several natural and development features related to past and present land use. Figure 3-1 displays the locations of surface features and drainage patterns. The Northern Bush River Area lies mostly north of 21st Street, bounded on the east by the Bush River, the south by Kings Creek, and the north by Lauderick Creek. The Bush River estuary tidally influences both creeks. Kings Creek flows southeast and converges with the Bush River at the southern portion of the peninsula. Lauderick



L E G E N D

Water
Road
Stream / Drainage Ditch
Surface Water Flow Direction

600 400 200 0 300 600 1200

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AND DRAINAGE

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Creek flows southeast and converges with the Bush River north of Eagle Point. The Bush River flows southward to the Chesapeake Bay.

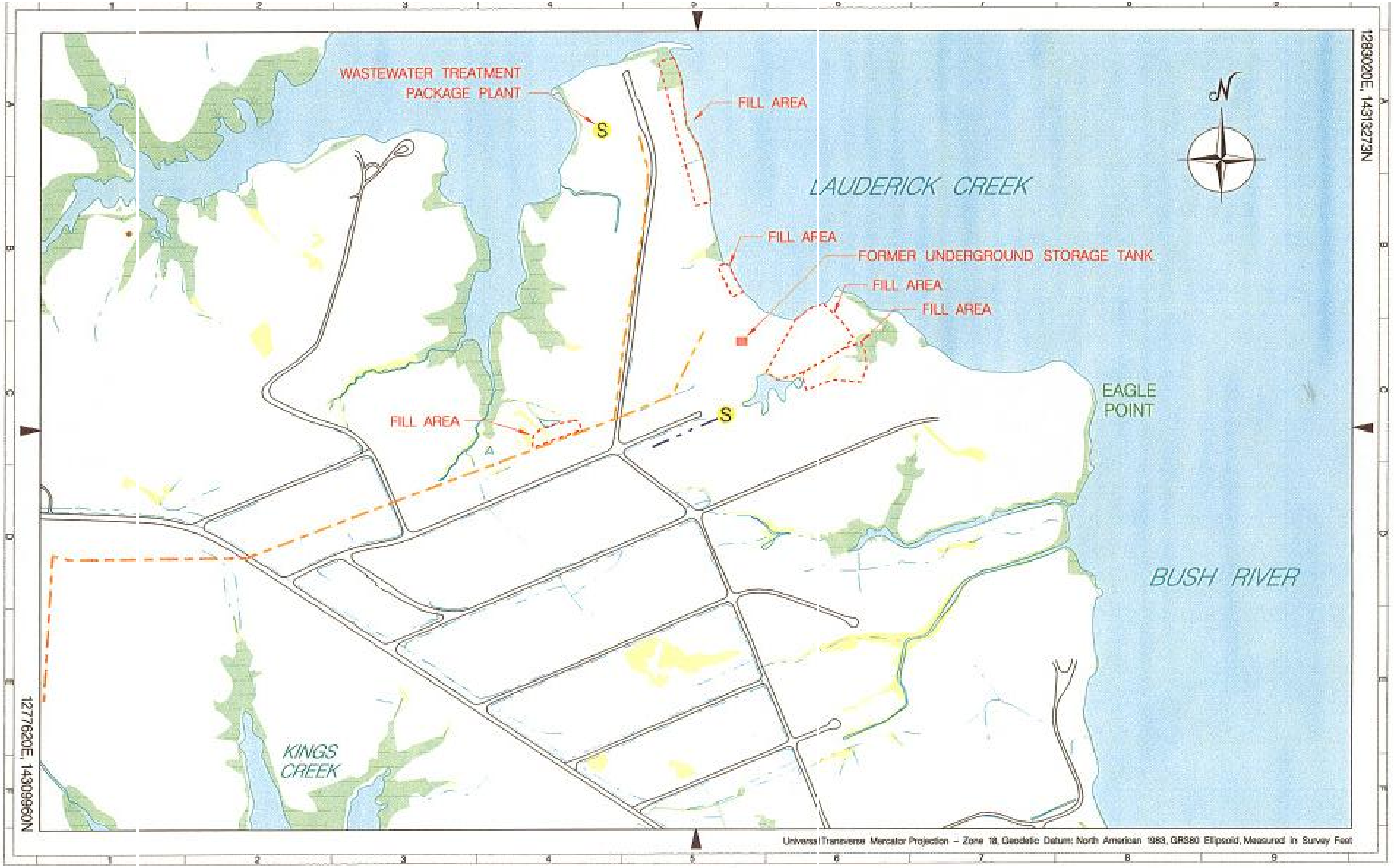
The Northern Bush River Area consists of approximately 55 percent secondary growth upland forest, 30 percent developed areas, 10 percent wetland areas, and 5 percent open grassy fields. Upland forest covers much of the northern, western, and southern portions of the peninsula. Woods and shrubs border the shorelines and wetlands of Lauderick Creek, Kings Creek and the Eagle Point area. Trees and open grassy areas surround the warehouses and storage yards. The west-central portion of the area contains open grassy fields. Open, overgrown alleys are in the rear of each warehouse, where rail spurs once existed from the old rail line that paralleled Bush River Road. Improved (asphalt paved) and unimproved (gravel) roads lead to warehouses, smaller buildings, graveled storage yards, the Boat Club, and the sites. Section 1.5 outlined site-specific information on development features.

Northern Bush River contains three localities of inland freshwater (palustrine) wetlands. The first inland wetland is a permanently flooded wetland with an unconsolidated bottom located east of building E2170. The second palustrine wetland is in the middle of the Cluster 35 area, a forested wetland that is seasonally flooded. The third palustrine wetland is located just inland from the northwestern shore of Kings Creek. Brackish (estuarine) wetlands are found along shorelines of the northwestern edge of the Cluster 35 area, along the shoreline of a Lauderick Creek tributary between Clusters 35 and 7, on the northernmost area of Cluster 7, and on the northwestern-most shores of Kings Creek (U.S. Fish and Wildlife Service 1981; Earth Tech, Inc., 1996).

Average ground surface elevation in the Northern Bush River Area is approximately 15 feet above msl. The topographic high of approximately 25 feet above msl is approximately 600 feet north of 19th Street. The land surface in the middle of the area is generally level. Steeper slopes are found along the northernmost shorelines. Shoreline stabilization work in 1997 placed large boulders and rock gabions for erosion control around the Eagle Point shoreline. All wetlands receive surface runoff and drainage from culverts and gullies of the inland areas. Figure 3-1 also displays arrows that show the surface water flow directions. Stormwater drainage from developed areas mostly feeds into intermittent streams or drainage ditches that lead into wetlands. A few intermittent streams discharge directly into surface water.

3.3 Subsurface Features

Figure 3-2 displays the known subsurface features in the Northern Bush River Area to include: the Cluster 7 Boat Club Fill Sites 9A, 9B, 9C, and 9D, a removed UST at the Boat Club, and the wastewater treatment package plant septic tank and chlorination chamber associated with the



LEGEND

- Water
- Road
- Tidal Wetland
- Non-tidal Wetland
- Stream / Drainage Ditch
- Fill Area
- S Septic Tank
- Septic Line
- Sanitary Sewer Line

600 400 200 0 300 600 1200

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SUBSURFACE FEATURES MAP

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B. JOYCE	T. DEREAMER	02-07-02	3-2

former Bio-Sensor Research Facility; a fill area north of warehouse E2168; and the septic tank and line associated with building E2169. Utilities include stormwater drainage culverts, and water lines that serve buildings and hydrants. Two, 6-inch-diameter metal pipes (believed to be part of and old water line) with unusual caps protrude above ground in the woods south of building E2194. A sanitary sewer line runs from the Boat Club restrooms westward (immediately north of warehouses E2166, E2168, and E2170) to connect with the sewer line from building E2190 on the northern end of the Cluster 7 Boat Club Fill Sites, and continues southwest through a clearing in the Cluster 36 DPW Southwest Storage Areas towards the Edgewood Area Wastewater Treatment Plant.

3.4 Geology

Harford County spans two physiographic provinces, the Piedmont and Atlantic Coastal Plain. The Piedmont contains crystalline basement rocks of Precambrian (more than 570 million years ago [Ma]) and early Paleozoic age. In the Atlantic Coastal Plain, unconsolidated sediment consisting of clay, silt, sand, and gravel of Cretaceous, Tertiary, and Quaternary age (144 Ma to recent) unconformably overlie the crystalline rocks. The division between these provinces is known as the Fall Line. APG lies southeast of the Fall Line. Sediment beneath APG is part of the thick sequence of unconsolidated sediment that forms the Atlantic Coastal Plain. Structurally, this sediment fills the Salisbury Embayment; a deep-seated basement structure that is perpendicular to the Atlantic coast. Dipping to the southeast at approximately 25 to 65 feet per mile, this embayment extends beneath the Delmarva Peninsula and into the Atlantic Ocean. Table 3-1 presents the generalized stratigraphy of the coastal plain in Harford County, Maryland.

Atlantic Coastal Plain sediment in Harford County was deposited by the actions of streams, rivers, and seas, and forms a wedge-shaped body that dips southeastward. This sediment outcrops at APG and comprises three stratigraphic units. From oldest to youngest, the units are the Potomac Group of Cretaceous age (65 to 135 Ma), the Talbot Formation of Pleistocene age (approximately 10,000 years to 2 Ma), and Holocene (i.e., less than 10,000 years ago) alluvium. A major unconformity occurs between the Pleistocene and Cretaceous sediments. Missing from the geologic record are sediments deposited during the Upper Cretaceous and Tertiary Periods (i.e., 2 to 65 Ma). Removal of these sediments from the APG area was probably due to erosion by earlier Susquehanna River systems during the Late Tertiary or Early Pleistocene Periods. The Potomac Group is undifferentiated in Harford County and consists of sand and gravel interbedded with multicolored clay. The Talbot Formation is extremely variable because of the changing thickness of clay and sand facies and the presence of clay interbeds in gravelly sand facies. Alluvial deposits occur adjacent to and within drainage ways and topographic lows (Maryland Geological Survey, 1968a, 1968b, 1969, 1993; USACE, Waterways Experiment Station, 1997).

Table 3-1. Generalized Stratigraphy of the Coastal Plain in Harford County, Maryland

System	Series	Group	Formation	Generalized Stratigraphy	Water-Bearing Properties
Quaternary	Holocene (Recent)		Alluvium	Clay, sand, silt, and gravel	Could yield large quantities of water where recharge can be induced from nearby streams
	Pleistocene		Talbot	Fine to medium silty-sand with mixtures of fine gravel and lenses of silt and clay; localized areas of marine silty clay unit	Water table aquifer where composed of coarse grained water-bearing materials, as in Aberdeen and Havre de Grace areas; yields up to 500 gallons per minute
Cretaceous	Lower Cretaceous	Potomac	Patapsco	Fine to medium, sand, silt, and clay	Yields some water to domestic wells in Harford County
			Arundel	Silty-clay to clayey-silt with lenses of organic silty-clay and traces of lignite and ironstone nodules	Not a water-bearing formation, except where penetrated by a few wells in outcrop area
			Patuxent	Fine to medium sands and gravels intercalated with silt and clay lenses	Source of water for numerous domestic and small commercial groundwater supplies along U.S. Highway 40; thickens rapidly toward southeast and becomes an excellent aquifer yielding up to 1,000 gallons per minute
Pre-Cambrian	Glenarm		Wissahickon and others	Bedrock	Not a water-bearing formation.

Source: U.S. Army Corps of Engineers, Waterways Experiment Station, 1997.

3.5 Hydrogeology

Five deep geotechnical borings drilled in the Bush River Study Area (as seen on Figure 1-3) supplement data collected during the RI. The encountered sediment displays interbedded clays, silts, sands, and gravel facies. These sediment combinations form three distinguishable aquifers separated by confining units in the Bush River Study Area: the surficial aquifer, the Canal Creek aquifer, and the lower confined aquifer. Figure 3-3 displays a stratigraphic cross section of the Bush River Study Area.

The first significant water-bearing unit of the Bush River Study Area is the surficial (water table) aquifer, which thins to the northwest and thickens to the south-southeast. The surficial aquifer is mostly unconfined or semiconfined, with some instances of confined situations. This aquifer overlays a dense clay and silty-clay confining unit. Pleistocene streams created by past drainage patterns of the Bush River have eroded sections of clay layers in the surficial aquifer and the clay confining unit below the surficial aquifer. This erosion, followed by subsequent deposition of permeable sediment, created paleochannels, increasing the depth and dimensions of the surficial aquifer. In some instances, paleochannels could breach clay layers within the surficial aquifer and/or the clay confining unit at the base of the surficial aquifer. A clay layer and/or unit breach causes hydraulic connections between sections of the surficial aquifer or between the surficial aquifer and the underlying Canal Creek aquifer. Geological and geophysical information shows paleochannels exist in the eastern and southern portions of the Bush River Study Area peninsula. Based on current geological and hydrogeological investigations, the clay confining unit underlying the surficial aquifer is continuous, with a varied thickness that averages 30-feet thick.

The Canal Creek aquifer lies immediately below the first encountered clay confining unit. This aquifer is confined throughout the study area. The Canal Creek aquifer sediment follows a southeastern dip causing this aquifer to be shallow in the north of the Bush River Study Area at 30 feet below msl and deeper in the south of the study area at 80 feet below msl.

A second confining unit separates the Canal Creek aquifer from the third aquifer discovered in the geotechnical boring investigations. This lower confined aquifer is at an average depth of 140 feet below msl.

Data collected from the geotechnical borings, and the Northern Bush River monitoring wells and abandoned borings provide information for constructing cross sections. Cross sections are based on interpretations of the stratigraphic relationship between sedimentary units, pollen and grain size

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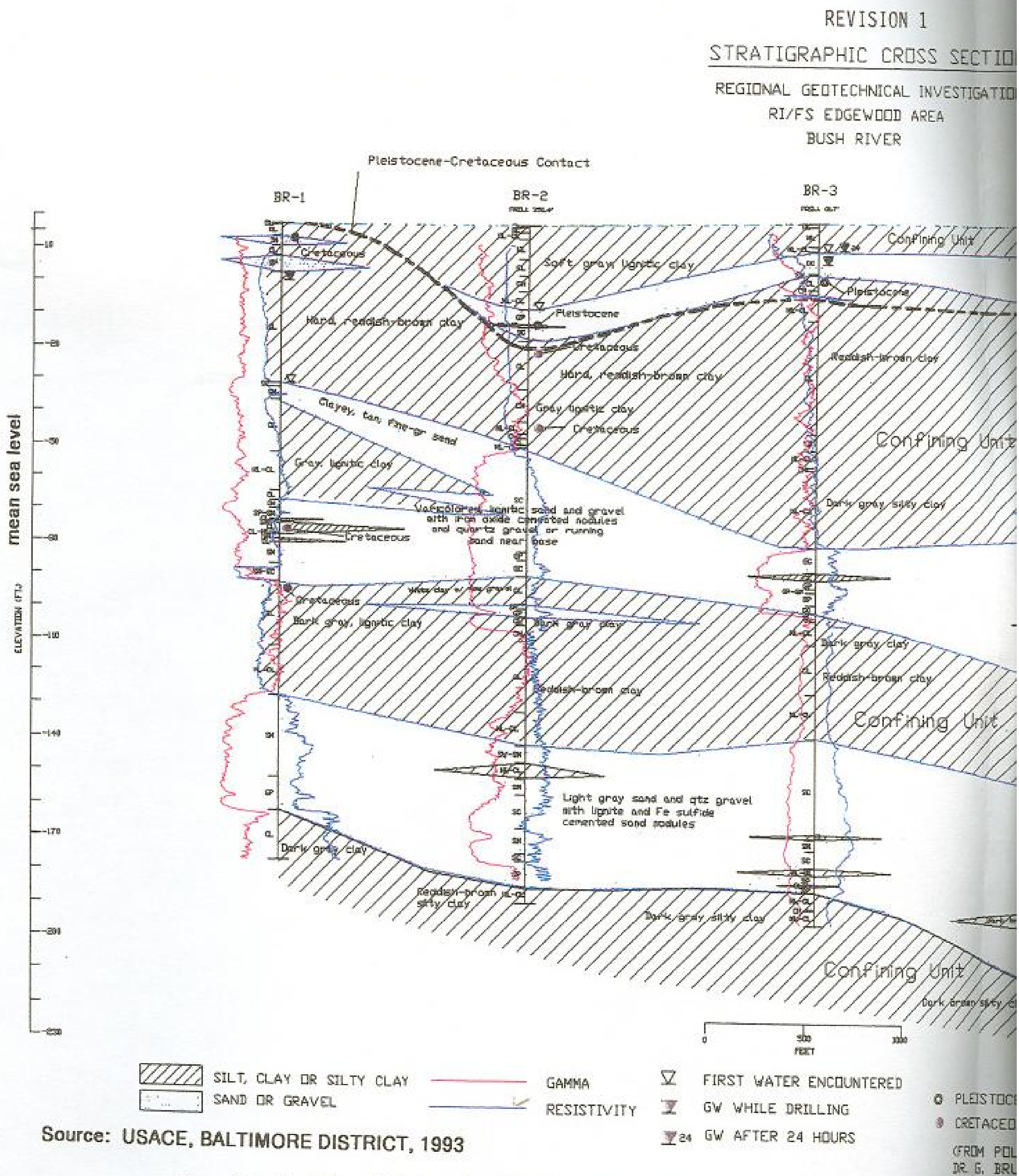


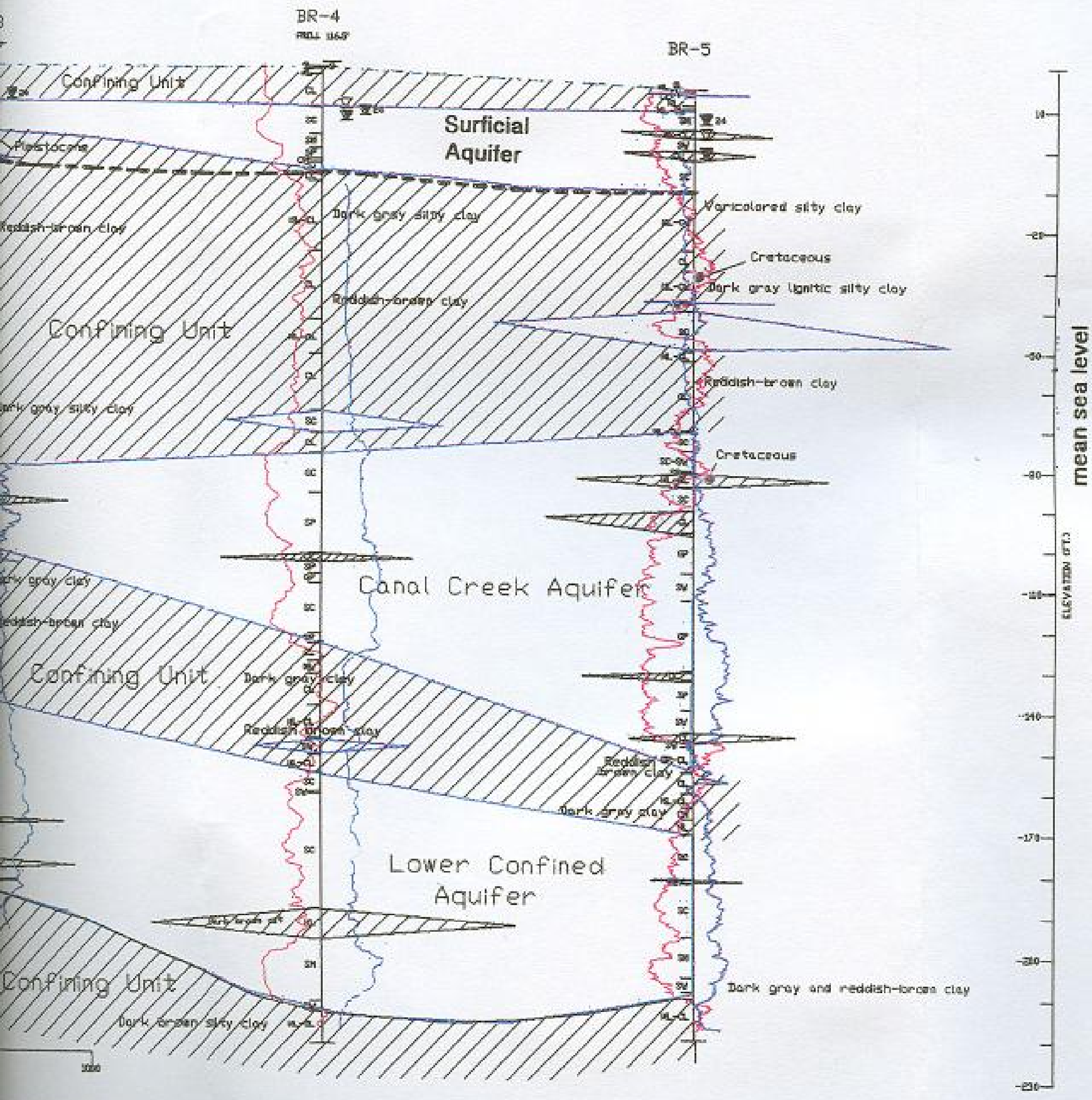
Source: USACE, BALTIMORE DISTRICT, 1993

Figure 3-3. Bush River Study Area Stratigraphic Cross Section

EVISION 1

HIC CROSS SECTION

ECHNICAL INVESTIGATION
DGEWOOD AREA
H RIVER



NCOUNTERED
LING
OURS

PLEISTOCENE
CRETACEOUS
(FROM POLLEN & SPORE ANALYSIS;
DR. G. BRUSH, JOHNS HOPKINS UNIV)

VERTICAL EXAGERATION = 12X

AFTER THURMOND, 1993

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analyses of subsurface samples, and hydrogeologic characteristics of the units. Figure 3-4 displays the traverses of four cross sections. Figures 3-5 through 3-8 present cross sections A-A', B-B', C-C', and D-D'.

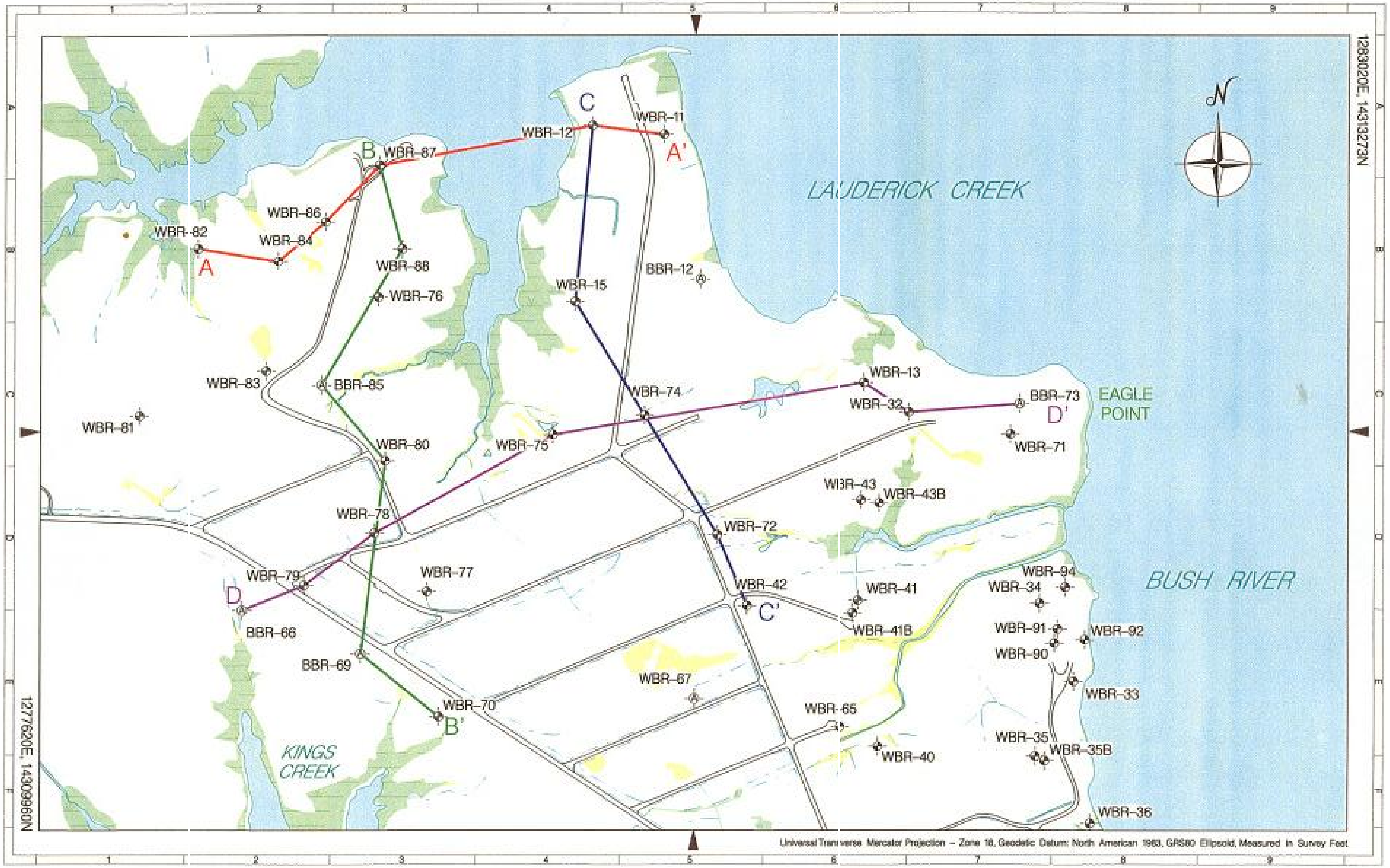
Water level measurements, slug tests, geophysical investigations, and physical testing of stratigraphic samples assist in defining the hydrogeologic setting of Northern Bush River. Physical tests of subsurface samples provide infiltration and permeability characteristics of the vadose zone, the surficial aquifer, and confining layers and units. Surficial aquifer potentiometric surface maps establish flow directions and recharge and discharge areas. Slug testing of wells provides an estimate of the hydraulic conductivity of the aquifer (Driscoll, 1989).

3.5.1 Surface Soil and Unsaturated Zone

Surface soil in the Northern Bush River Area mainly consists of silt with varying amounts of clay, very fine and fine grain sand, and some organics. The surface soil in the Northern Bush River Area is classified through (1) examination of the top two feet recorded in the borehole logs for existing monitoring wells and abandoned borings and (2) through field classification of surface soil samples. Thirty surface soil samples were field classified with universal soil classification descriptions. Along the shoreline adjacent to the Bush River, surface soil is dominated by sandy-silt and silty-sand. Sandy-silt, clayey-silt, and silty-clay comprise the majority of the surface soil within the interior portions of the Northern Bush River Area.

Surface soil erosion results in similar soil types found in sediment within and around the Northern Bush River Area. Sediment surrounding the shorelines tend to be sand with less organic content. Thirteen sediment and 15 soil samples were tested for total organic carbon content. Table 3-2 lists each sample with their percentage weight of total organic carbon content. In general, sediment and soil samples (e.g., C07-SD-04 and C07-SS-04) near some marshes contain higher amounts of total organic carbon (10.6 to 13.6 percent). Sediment and soil samples (e.g., C07-SD-01 and C07-SO-13) with more sand contents contain lower amounts of total organic carbon (0.4 to 1.7 percent). The percentage of organic matter ranges from 0.2 to 13.6 percent, with a mean of 2.55 percent.

Interpretations of the unsaturated (vadose) zone are based on descriptions from borehole logs and grain size analysis of samples above the saturated zone. The vadose zone in the Northern Bush River Area ranges in thickness from 3 to 15 feet, and averages 9-feet-thick. The vadose zone at the northern end of Cadwalader Road near the Cluster 7 Bio-Sensor Research Facility consists of mostly sandy-clay and sandy-silt. Silty-sand predominates in the vadose zone south and west of building E2194 and the Cluster 35 DPW Storage Areas Site 22A. The higher sand contents within the vadose zone increase the degree of aeration and vertical infiltration to the surficial aquifer. The



LEGEND

	Road		Site Boundary
	Water		Tidal Wetland
	Stream / Drainage Ditch		Non-tidal Wetland
	Abandoned Well or Boring		Monitoring Well

600 400 200 0 300 600 1200

GRAPHICAL SCALE
IN FEET (1" = 600')

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TITLE:
NORTHERN BUSH RIVER
CROSS SECTION TRAVERSES

CARTOGRAPHER:	APPROVED BY:	DATE:	FIGURE:
B. JOYCE	T. DEREAMER	01-22-03	2-4

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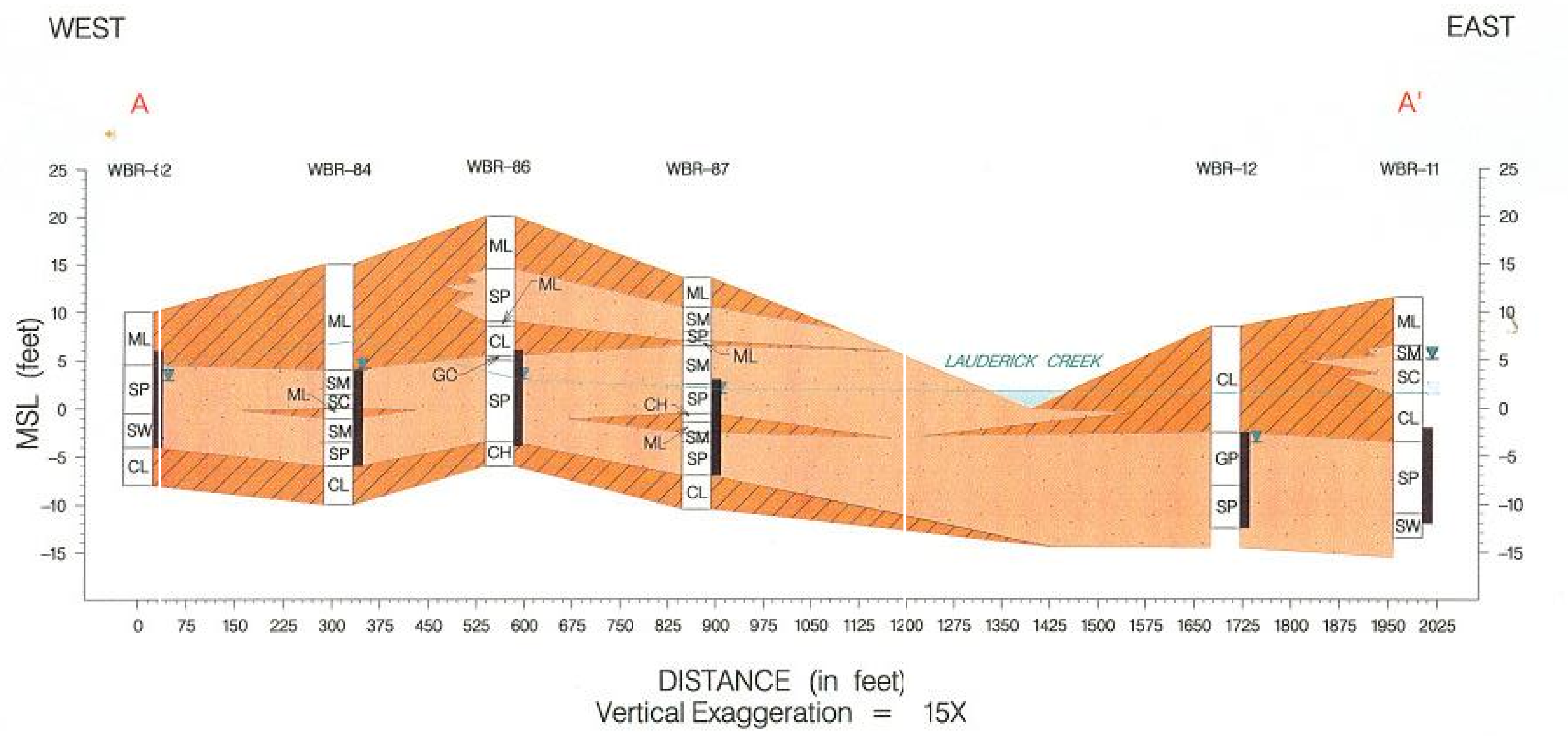

LEGEND

Clay/Silt	Static Water Level June 24, 1996
Sand	ML (Silt)
Water Encountered	CL (Clay)
Well Screen	SC (Clayey Sand)
	CH (Inorganic Clays)
	SM (Silty Sands)
	SP (Poorly Graded Sand)
	GC (Clayey Gravel)

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TITLE:

GEOLOGIC PROFILE A–A'

DRAWN BY:	GEOLOGIST:	DATE:	FIGURE:
B. JOYCE	T. DEREAMER	02-08-02	3-5

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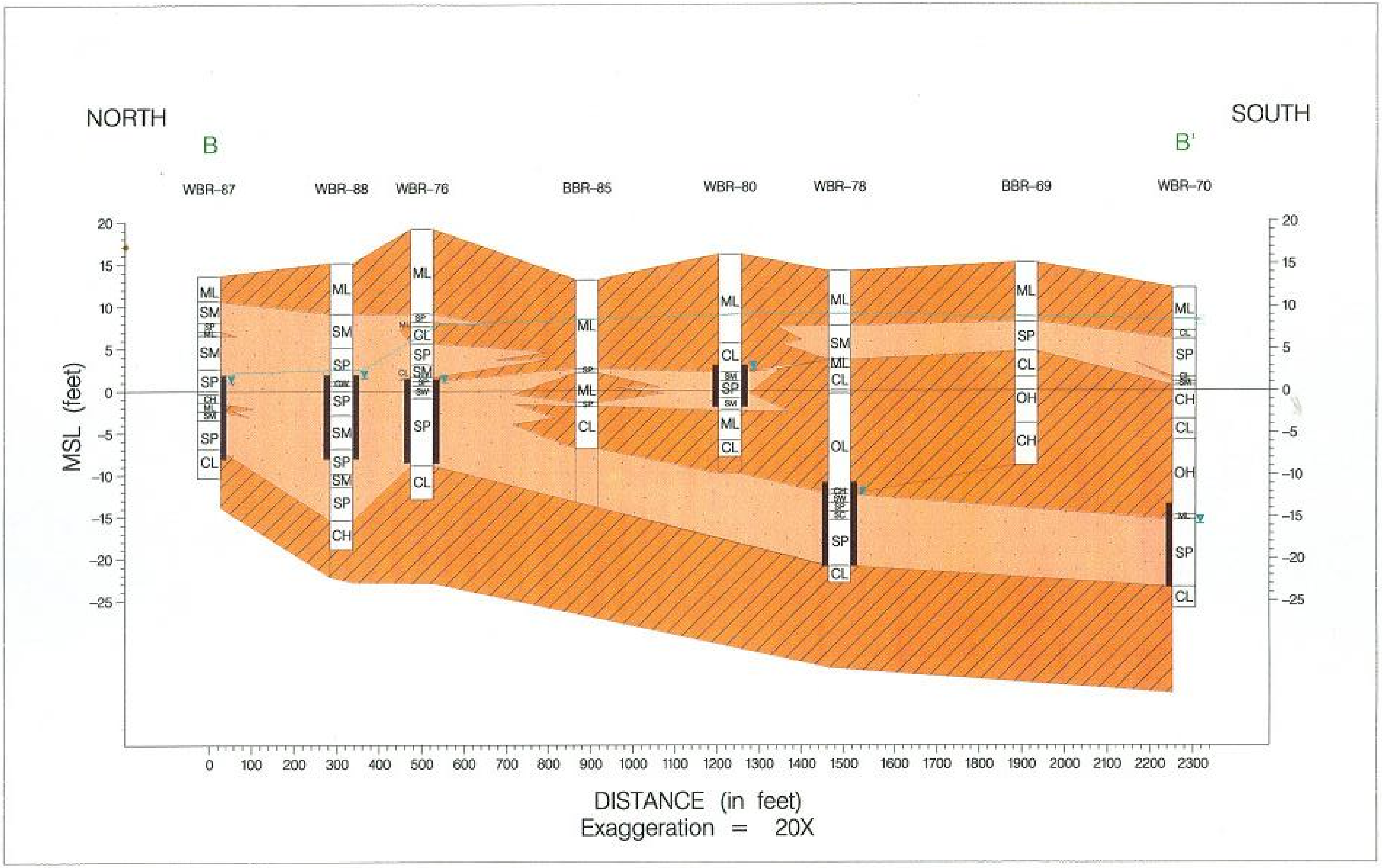

LEGEND

- Clay/Silt
- Sand
- Water Encountered
- Well Screen
- Static Water Level June 24, 1996
- ML (Silt)
- CL (Clay)
- SC (Clayey Sand)
- OL (Organic Silt)
- CH (Inorganic Clay)
- SM (Silty Sand)
- SP (Poorly Graded Sand)
- GW (Well Graded Gravel)
- OH (Inorganic Clay)

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TITLE:
NORTHERN BUSH RIVER
CROSS SECTION B-B'

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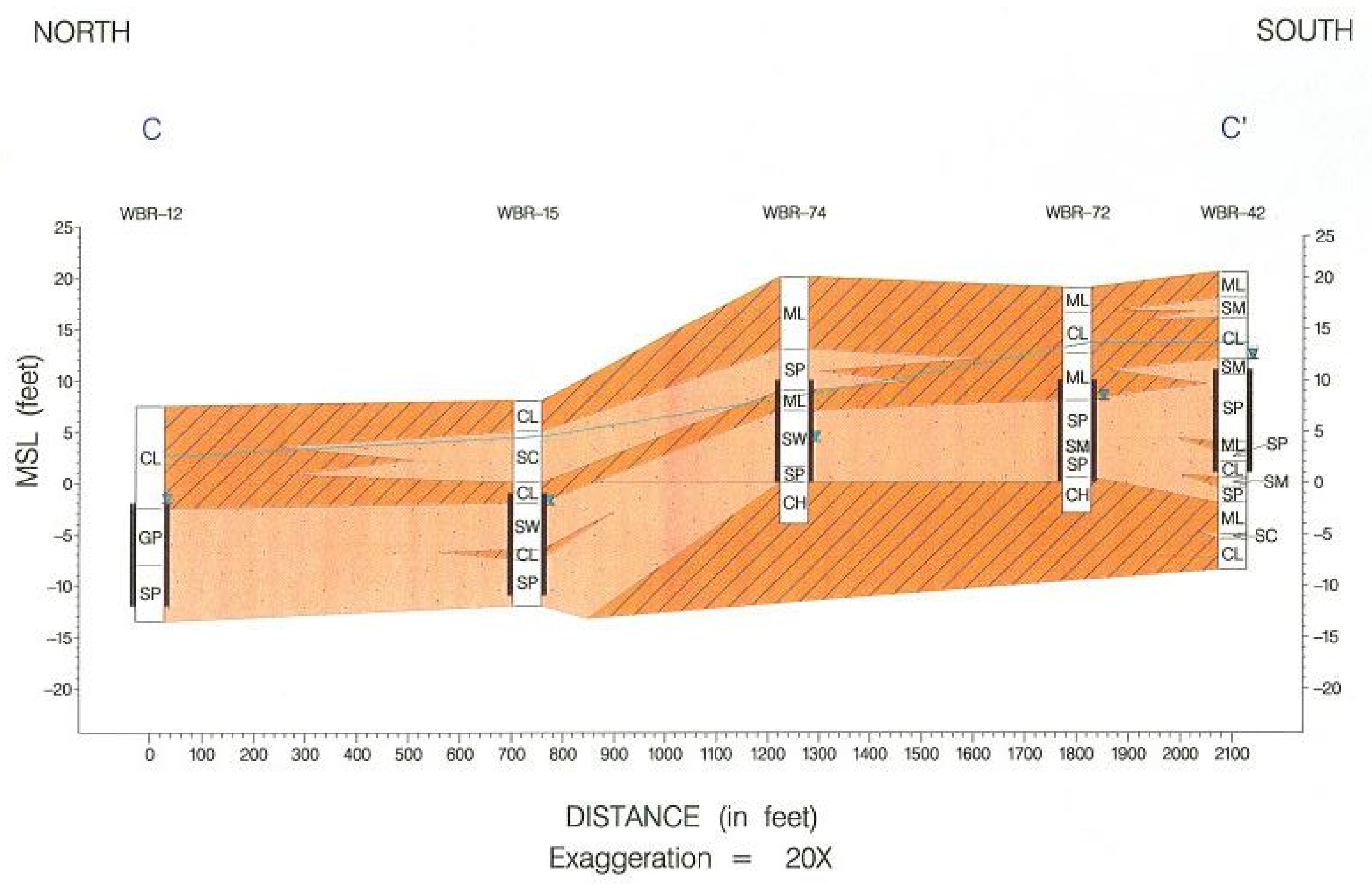

L E G E N D

Clay/Silt	Static Water Level June 24, 1996	CH (Inorganic Clays)
Sand	ML (Silt)	SM (Silty Sands)
Water Encountered	CL (Clay)	SP (Poorly Graded Sand)
Well Screen	SC (Clayey Sand)	GC (Clayey Gravel)
		OL ORGANIC SILT

SCALE AS SHOWN

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TITLE:
NORTHERN BUSH RIVER
CROSS SECTION C-C'

DRAWN BY:	GEOLOGIST:	DATE:	FIGURE:
B. JOYCE	T. DEREAMER	02-08-02	3-7

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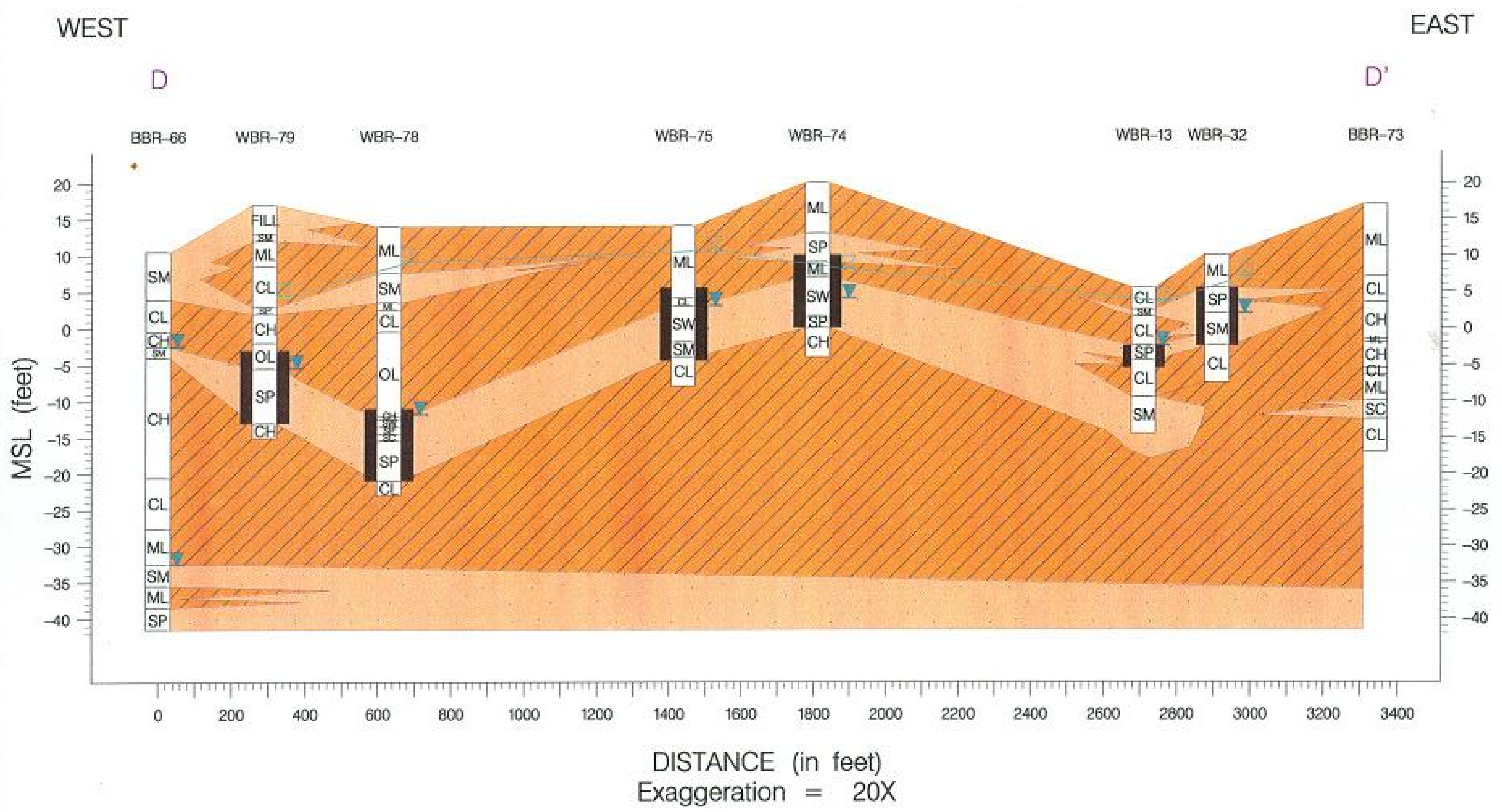

L E G E N D

Clay/Silt
Sand
Water Encountered
Static Water Level June 24, 1996
ML (Silt)
CL (Clay)
SC (Clayey Sand)
CH (Inorganic Clays)
SM (Silty Sands)
SP (Poorly Graded Sand)
OL ORGANIC SILT

SCALE AS SHOWN

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TITLE:

NORTHERN BUSH RIVER
CROSS SECTION D-D'

DRAWN BY:	GEOLOGIST:	DATE:	FIGURE:
B. JOYCE	T. DEREAMER	02-08-02	3-8

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Table 3-2. Total Organic Carbon Content of Sediment and Soil

Sample Number	Total Organic Carbon (percent)	Sample Number	Total Organic Carbon (percent)
C07-SD-01	0.4	C07-SO-01	2.0
C07-SD-02	2.9	C07-SO-02	0.7
C07-SD-03	0.2	C07-SO-03	2.5
C07-SD-04	13.6	C07-SO-08	1.7
C07-SD-05	4.8	C07-SO-10	3.0
C36-SD-01	2.3	C07-SO-11	2.5
C36-SD-02	3.2	C07-SO-12	2.3
C36-SD-03	0.2	C07-SO-13	1.7
C36-SD-04	0.3	C07-SS-04	10.6
C35-SD-01	1.0	C07-SS-05	1.4
C35-SD-02	3.4	C07-SS-06	0.8
C35-SD-03	1.8	C07-SS-07	0.6
C35-SD-04	1.1	C07-SS-14	3.6
		C07-SS-15	1.2
		C07-SS-16	1.6

SD Sediment sample designation
SO Subsurface soil (composite interval 6 inches to 3.5 feet) sample designation
SS Surface soil sample designation

majority of the vadose zone east of Cadwalader Road toward Eagle Point consists of clayey-silt with trace amounts of fine grain sand. Silt predominates within the vadose north of 19th and 20th Streets toward the middle Lauderick Creek tributary.

The absence of sand in these clayey-silts and silts decreases aeration and vertical infiltration to the aquifer. The vadose zone around and north of the Cluster 35 DPW Storage Areas Sites 2B and 2C toward the western Lauderick Creek tributary consists of interfingered mixtures of sands, silts, and clays. These mixtures yield alternating layers of more permeable and less permeable sediment. Surface runoff infiltration into the vadose zone will seek the path of least resistance into the surficial aquifer. Layers within the vadose zone with lower vertical hydraulic conductivities (clay and silt) will cause infiltrating water to move horizontally in the unsaturated zone. This horizontal movement or interflow of infiltrating water in the vadose zone will continue until reaching an area with higher vertical hydraulic conductivity (Fetter, 1988).

3.5.2 Surficial Aquifer

The surficial aquifer in the Northern Bush River Area consists of interfingered sands, clays, and silts. The complexity of the surficial aquifer is due to cyclic successions of fluvial and marginal marine erosion and deposition processes. Fluctuating periods of erosion and deposition have produced a complex layering of sediment with variable hydraulic properties. Surficial aquifer sediment displays sequences of upward fining characteristics. These upward fining characteristics and the presence of interfingered silt and clay lenses or layers are both typical of a fluvial depositional environment (Miall, 1982).

Four cross sections present representations of the surficial aquifer setting within the Northern Bush River Area. Cross section A-A' (Figure 3-5) traverses from west to east along the northern portion of the area. Cross section B-B' (Figure 3-6) traverses from north to south along the western portion of the area. Cross section C-C' (Figure 3-7) traverses from north to south along the eastern portion of the area. Cross section D-D' (Figure 3-8) traverses from west to east along the middle portion of the area. Throughout the northern, eastern, and middle portions of the Northern Bush River Area the surficial aquifer is unconfined or semi-confined. Confined situations are mainly in the western portion of the Northern Bush River Area and near Kings Creek. The specific sediment that comprises the surficial aquifer consists of mostly poorly graded sands, within zones of silty-sands and well-graded sands. A less than 1-foot thick, well-sorted gravel lense lies at 14 feet below the ground surface in well WBR-88 on cross section B-B' (Figure 3-6). Five feet of poorly graded gravels lie in the upper portion of the aquifer at well WBR-12 on cross section C-C' (Figure 3-7).

The average depth to the surficial aquifer is 10 feet below the ground surface. The saturated thickness of the surficial aquifer averages 12 feet. The saturated thickness of the surficial aquifer in the middle portion of the area ranges from 7 feet at well WBR-75 on cross section D-D' (Figure 3-8) to greater than 18 feet in the northeastern portions of the area at wells WBR-11 and WBR-12 on cross section A-A' (Figure 3-5). The thinnest part of the aquifer occurs in the middle and western portions of the area. The thickest part of the aquifer occurs in the northern portion of the Cluster 7 Bio-Sensor Research Facility site on cross sections A-A' (Figure 3-5) and C-C' (Figure 3-7), where paleochannel erosion and deposition have increased the depth of the surficial aquifer.

The aquifer at many locations is divided into an upper and lower section by laterally discontinuous silt and clay layers or lenses. The hydraulic conductivity of these dividing layers, or lenses, becomes very important when discussing the hydraulic continuity of the surficial aquifer. For example, the northwestern portion of the area at well WBR-87 on cross section A-A' (Figure 3-5) contains a 1-foot-thick silt lense at 6 foot below the ground surface, and 7-foot-thick, silty-sand and clayey-silt lense at 15 feet below the ground surface. The thin nature and high sand content of these silty lenses allows vertical hydraulic connection and infiltration between the upper and lower sections of the aquifer. In the southwestern portion of the area, a middle silt and clay layer that separates the aquifer becomes very dense, hindering the vertical hydraulic connections between sections of the aquifer. Wells WBR-78 and WBR-70 on cross section B-B' (Figure 3-6) encountered an 18-feet-thick silt and clay layer at 10 feet below the ground surface. This thicker and denser layer separates an unconfined upper section from the lower section of the surficial aquifer. These silt and clay layers and lenses that divide the surficial aquifer into upper and lower sections are defined on the cross sections based on data collected during borehole logging and the saturated characteristics of sediments encountered.

With the exception of borings at wells WBR-11 and WBR-12 on cross section A-A' (Figure 3-5) and well WBR-15 on cross section C-C' (Figure 3-7), all other borings encountered a clay confining unit that defines the base of the Northern Bush River surficial aquifer. The irregular surface of the confining unit generally dips in a southeastern trend, as seen on cross section B-B' (Figure 3-6). This upper confining unit separates the surficial aquifer from the deeper underlying confined Canal Creek aquifer. Abandoned boring BBR-66 on cross Section D-D' (Figure 3-8) encountered a thin (less than 2-foot-thick) water-bearing unit lying over a 32-foot-thick clay confining unit. The bottom of the boring encountered the Canal Creek aquifer at 43 feet below the ground surface.

3.5.3 Groundwater Flow Direction and Hydraulic Properties

Synoptic water level measurements are available for three dates from the surficial aquifer monitoring wells in the Bush River Study Area. Water level measurements were collected on March 6, June 24, and October 11, 1996. The water levels are subtracted from the surveyed well riser elevations to determine the surficial aquifer groundwater elevations at each well. Table 3-3 presents well riser elevations, three periods of water level measurements, and corresponding groundwater elevations. Figures 3-9 through 3-11 display three surficial aquifer potentiometric surface maps designed from the data in Table 3-3.

The first two surficial aquifer potentiometric surface maps (Figures 3-9 and 3-10) display seasonal high groundwater elevations during the wet periods of March and June 1996. Figure 3-11 displays the seasonal low groundwater elevations for the drier period of October 1996. Even with the noticeable changes in groundwater elevations, comparison of the potentiometric surface maps shows slight variations in groundwater flow directions during the low verses high seasonal influences. Recharge areas for the surficial aquifer include the middle portion of the peninsula, and the unconfined and semi-confined areas within Northern Bush River.

Groundwater flow within the Northern Bush River Area is split into three broad subsurface drainage divides, allowing the flow to form a radial pattern outward towards Lauderick Creek and Kings Creek. Groundwater flows from middle of the peninsula and splits to flow to the north and northeast toward Lauderick Creek, and southwest toward Kings Creek. In the south-central portion of the Northern Bush River Area, the main, north-south trending divide forms in the middle of the peninsula. This broad divide directs the groundwater flow east towards Bush River, north towards Lauderick Creek, and southwest towards Kings Creek. A broad northwest-southeast trending divide forms between of 19th and 20th Streets. A prominent, east-west trending divide lies in the western portion of the area. Both of the divides direct groundwater north toward the middle Lauderick Creek tributary and south toward the Kings Creek tributary.

June 1996 groundwater elevations were collected following multiple events of intense rainfall. Figure 3-10 displayed the surficial aquifer potentiometric surface map created from the June 1996 data. The increase of rainfall over a short period of time increased the amounts of stormwater overland and runoff flow across the Bush River peninsula. Many of the depression storage areas, marsh areas, and intermittent and perennial streams became flooded. In comparing the June to the March 1996 map (Figures 3-10 and 3-9), the majority of the wells with higher topographic elevations (above msl) had higher groundwater elevations in March 1996. The groundwater elevations for some wells near Lauderick Creek (e.g., WBR- 11, -12, -13, -87, -88, and –76) increased during June 1996 by an average of over a 0.5 foot. This increase of

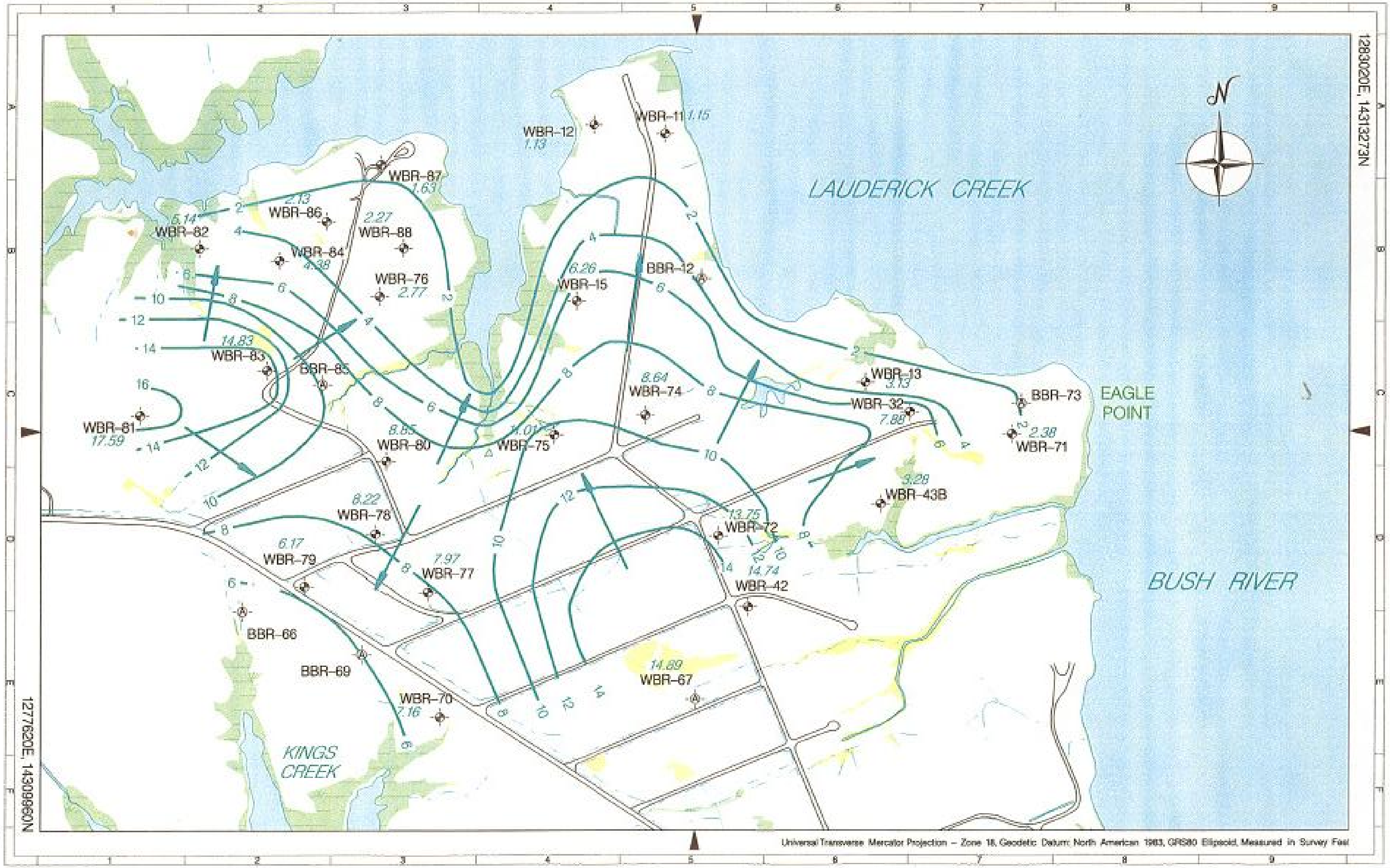
Table 3-3. Surficial Aquifer Groundwater Elevations

Well Number	Top of Riser Elevation (feet msl)	Water Level on 3/6/96 (feet)	Groundwater Elevation for 3/6/96 (feet msl)	Water Level on 6/24/96 (feet)	Groundwater Elevation for 6/24/96 (feet msl)	Water Level on 10/11/96 (feet)	Groundwater Elevation for 10/11/96 (feet msl)
WBR-11	13.25	12.10	1.15	11.38	1.87	11.54	1.71
WBR-12	9.49	8.36	1.13	7.63	1.86	7.80	1.69
WBR-13	7.52	4.39	3.13	4.12	3.40	4.28	3.24
WBR-15	11.08	4.82	6.26	6.99	4.09	4.83	6.25
WBR-70	14.46	7.30	7.16	7.06	7.40	6.98	7.48
WBR-74	22.34	13.70	8.64	8.00	14.34	14.18	8.16
WBR-75	15.59	4.58	11.01	5.24	10.35	5.51	10.08
WBR-76	20.66	17.89	2.77	13.94	6.72	15.35	5.31
WBR-77	17.27	9.30	7.97	9.00	8.27	9.09	8.18
WBR-78	16.45	8.23	8.22	8.01	8.44	8.12	8.33
WBR-79	19.15	12.98	6.17	14.70	4.45	13.74	5.41
WBR-80	18.59	9.74	8.85	10.21	8.38	10.52	8.07
WBR-81	27.95	10.36	17.59	11.04	16.91	11.98	15.97
WBR-82	12.63	7.49	5.14	7.72	4.91	7.46	5.17
WBR-83	19.94	5.11	14.83	6.36	13.58	5.60	14.34

Table 3-3. Surficial Aquifer Groundwater Elevations (Continued)

Well Number	Top of Riser Elevation (feet msl)	Water Level on 3/6/96 (feet)	Groundwater Elevation for 3/6/96 (feet msl)	Water Level on 6/24/96 (feet)	Groundwater Elevation for 6/24/96 (feet msl)	Water Level on 10/11/96 (feet)	Groundwater Elevation for 10/11/96 (feet msl)
WBR-84	17.58	13.20	4.38	10.72	6.86	12.18	5.40
WBR-86	22.16	20.03	2.13	19.35	2.81	19.73	2.43
WBR-87	16.22	14.59	1.63	14.24	1.98	14.33	1.89
WBR-88	17.08	14.81	2.27	14.38	2.70	14.6	2.48
Southern Bush River Monitoring Wells Used to Supplement Groundwater Contours							
WBR-67	21.73	6.84	14.89	9.17	12.56	8.72	13.01
WBR-42	22.07	7.33	14.74	8.88	13.19	9.80	12.27
WBR-72	21.95	8.20	13.75	8.81	13.14	9.38	12.57
WBR-43B	12.66	9.38	3.28	9.59	3.07	9.79	2.87
WBR-32	11.64	3.76	7.88	4.41	7.23	4.78	6.86
WBR-71	17.99	15.61	2.38	15.20	2.79	15.48	2.51

All elevations in feet mean sea level (National Geodetic Vertical Datum, 1929).



L E G E N D

- Water
- Tidal Wetland
- Non-tidal Wetland
- Road
- Monitoring Well
- Abandoned Well or Boring
- Stream / Drainage Ditch
- Groundwater Flow
- Groundwater Elevation Contour (ft MSL)

600 400 200 0 300 600 1200

GRAPHICAL SCALE
IN FEET (1" = 600')

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TITLE: NORTHERN BUSH RIVER SURFICIAL AQUIFER POTENTIOMETRIC SURFACE MAP MARCH 1996			
CARTOGRAPHER: B. JOYCE	APPROVED BY: T. DEREAMER	DATE: 01-23-03	FIGURE: 3-9

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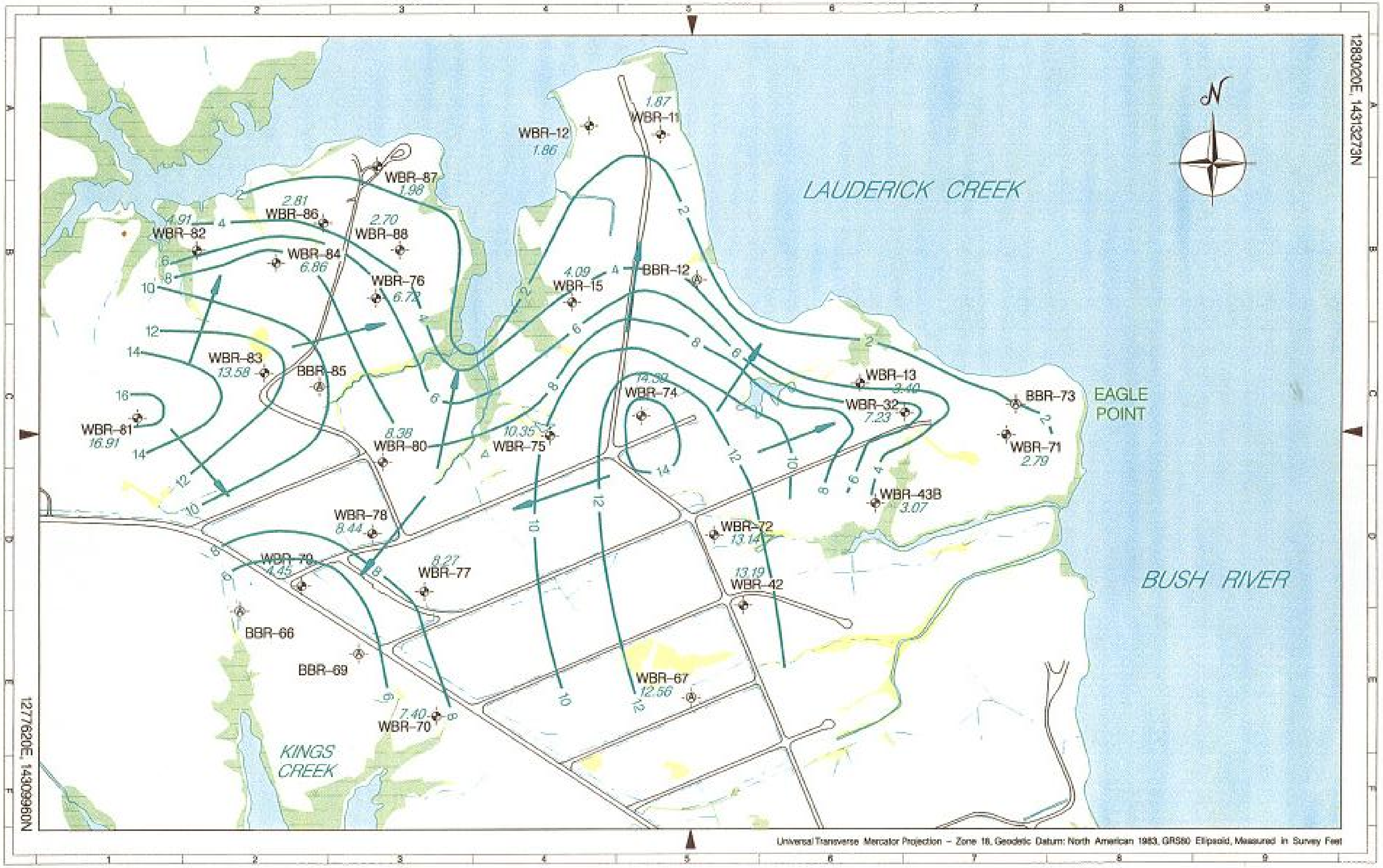

LEGEND

- Water
- Tidal Wetland
- Non-tidal Wetland
- Road
- Monitoring Well
- Abandoned Well or Boring
- Stream / Drainage Ditch
- Groundwater Flow
- Groundwater Elevation Contour (ft MSL)

600 400 200 0 300 600 1200

GRAPHICAL SCALE
IN FEET (1" = 600')

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TITLE:
NORTHERN BUSH RIVER
SURFICIAL AQUIFER
POTENTIOMETRIC SURFACE
JUNE 1996

CARTOGRAPHER:	APPROVED BY:	DATE:	FIGURE:
B. JOYCE	T. DEREAMER	01-23-03	10

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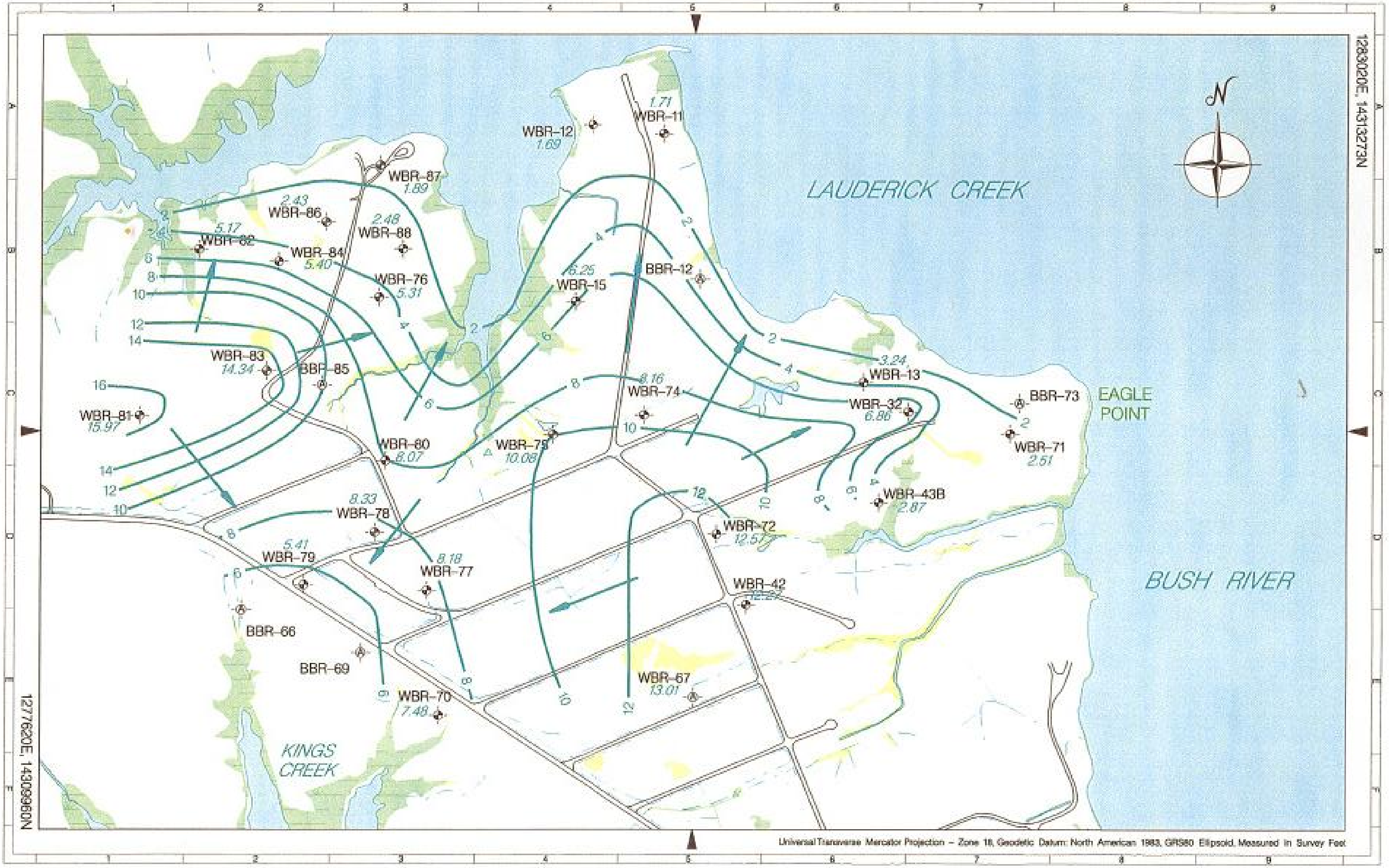

LEGEND

- Water
- Tidal Wetland
- Non-tidal Wetland
- Road
- Monitoring Well
- Abandoned Well or Boring
- Stream / Drainage Ditch
- Groundwater Flow
- Groundwater Elevation Contour (ft MSL)

600 400 200 0 300 600 1200

GRAPHICAL SCALE
IN FEET (1" = 600')

6095 Marshalee Drive
Elkridge, MD 21075
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TITLE:
NORTHERN BUSH RIVER
SURFICIAL AQUIFER
POTENTIOMETRIC SURFACE MAP
OCTOBER 1996

CARTOGRAPHER:	APPROVED BY:	DATE:	FIGURE:
B. JOYCE	T. DEREAMER	01-23-03	3-11

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